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Analysis of Earthquake Data from the Greater Los Angeles Basin and Adjacent Offshore Area, Southern California

U.S. Geological Survey Award No. 04HQGR0052

Element I & III

Key words: Geophysics, seismology, seismotectonics

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ABSTRACT

We synthesize and interpret local earthquake data recorded by the Caltech/USGS Southern California Seismographic Network (SCSN/CISN) in southern California. The goal is to use the existing regional seismic network data to: (1) refine the regional tectonic framework; (2) investigate the nature and configuration of active surficial and concealed faults; (3) determine spatial and temporal characteristics of regional seismicity; (4) determine the 3-D seismic properties of the crust; and (5) delineate potential seismic source zones. Because of the large volume of data and tectonic and geologic complexity of the area, this project is a multi-year effort and has been divided into several tasks.

RESULTS

Imaging the source region of the 2003 San Simeon earthquake within the weak Franciscan subduction complex, central California

Data collected from the 2003 Mw6.5 San Simeon earthquake sequence in central California and a 1986 seismic refraction experiment demonstrate that the weak Franciscan subduction complex suffered brittle failure in a region without significant velocity contrast across a slip plane. Relocated hypocenters suggest a spatial relationship between the seismicity and the Oceanic fault, although blind faulting on a nearby, unknown fault is an equally plausible alternative. The aftershock volume is sandwiched between the Nacimiento and Oceanic faults and is characterized by rocks of low compressional velocity (Vp) abutted to the east and west by rocks of higher Vp. This volume of inferred Franciscan rocks is embedded within the larger Santa Lucia anticline.

Pore fluids, whose presence is implied by elevated Vp/Vs values, may locally decrease normal stress and limit the aftershock depth distribution between 3 to 8 km within the hanging wall. The paucity of aftershocks along the mainshock rupture surface may reflect either the absence of a damage zone or an almost complete stress drop within the low Vp or weak rock matrix surrounding the mainshock rupture.

The 2003 San Simeon mainshock and its aftershocks provided the first extensive suite of travel-time data to image the western side of central Coast Ranges since the installation of modern seismic networks in the area (Figure 1). We determined detailed three-dimensional Vp and Vp/Vs velocity models of the region to investigate the relationship between the earthquake sequence and the Franciscan assemblage. The northwest striking pre-Quaternary Nacimiento and Holocene Oceanic faults cut across this central portion of the Santa Lucia. The mainshock rupture occurred on a fault subparallel to the Oceanic fault and propagated to the southeast for a distance of approximately 30 km with a maximum up-dip width of 4 to 8 km [*Ji et al.*, 2004]. The aftershocks lie between the Oceanic and Nacimiento faults, providing new data for crustal structure imaging and synthesizing seismotectonics.

The aftershocks that are distributed between both the footwall and the hanging wall occurred within a volume of similar lower Vp (5.0 - 5.8 km/s) but not along a clearly defined discontinuity in the velocity structure (Figure 2). The depth distribution of the aftershocks is mostly limited to the depth range of the mainshock slip, or 3 to 10 km. The upper limit of 3 km mostly coincides with the base of the near-surface low Vp sedimentary layer. Cross section (A) through the hypocenter of the mainshock, shows aftershock hypocenters associated with the NE dipping mainshock thrust as well as with a SW dipping back thrust [*Hardebeck and Michael*, 2004]. The 5 km/s Vp contour above the projection of the mainshock plane extends to a shallower depth than elsewhere, consistent with the uplift produced by the earthquake. Cross section (B) projects through the area of highest coseismic slip and an anomalously low Vp zone in the depth range of 5 to 9 km but shows no clear evidence of a NE-dipping zone of a dense cluster of aftershock surrounding the mainshock rupture. Low Vp Franciscan rocks imaged by the inversion appear to be confined to a trough between rocks with higher Vp to the west and east, suggesting overthrusting of the low Vp rocks. The cross section (C) is located just beyond the SE extent of the rupture. The two largest clusters of seismicity on this cross section indicate a possible SW-dipping thrust [*Hardebeck and Michael*, 2004]. Similarly, the aftershocks fall within regions of elevated Vp/Vs. This manuscript is published in Geophysical Research Letters, (Hauksson, et al., 2004).

Southern California Hypocenter Relocation with Waveform Cross-Correlation: Part 1. Results Using the Double-Difference Method

We present the results of relocating 327,000 southern California earthquakes that occurred between 1984 and 2002 (Figure 3). We apply time domain waveform cross-correlation for *P* and *S* waves between each event and 100 neighboring events identified from the catalog based on a three-dimensional (3D) velocity model. To simplify the computation, we first divide southern California into five polygons, such that there are ~100,000 events or less in each region. The polygon boundaries are chosen to lie in regions of sparse seismicity. We calculate and save differential times from the peaks in the cross-correlation functions and use a spline interpolation method to achieve a nominal timing precision of 0.001 s. These differential times, together with existing *P* and *S* phase picks, are input to the double-difference program of Waldhauser and Ellsworth (2000, 2002) to calculate refined hypocenters. We divide the southern California region into grid cells and successively relocate hypocenters within each grid cell. The overall resulting pattern of seismicity is more focused than the previously determined pattern from 1D or 3D models. The new improved locations are more clustered, in many cases by a factor of two or three, and often show clear linear alignments. In particular, the depth distribution is improved and less affected by layer boundaries in velocity models or other similar artifacts. This manuscript is in press in BSSA and will appear in the June 2005 issue.

PUBLICATIONS and REPORTS

Fuis, G.S, R.W. Clayton, P.M. Davis, T. Ryberg, W.J. Lutter, D.A. Okaya, E. Hauksson, C. Prodehl, J.M. Murphy, M.L. Benthien, S.A. Baher, M.D. Kohler, K. Thygesen, G. Simila, and G.R. Keller, Fault systems of the 1971 San Fernando and 1994 Northridge earthquakes, southern California: Relocated aftershocks and seismic images from LARSE II, *Geology, 31, no.2,* p. 171-174, 2003.

Hauksson, E., D. Oppenheimer, and T. M. Brocher. Imaging the source region of the 2003 San Simeon earthquake within the weak Franciscan subduction complex, central California, Geophys. Res. Lett., 31, L20607,doi:10.1029/2004GL021049, 2004.

Hauksson, E. and P. Shearer, Southern California Hypocenter Relocation with Waveform Cross-Correlation: Part 1. Results Using the Double-Difference Method, in press, *Bull. Seismol. Soc. Am.,* 2005.

Shearer, P., E. Hauksson, and G. Lin Southern California Hypocenter Relocation with Waveform Cross-Correlation: Part 2. Results Using Source-Specific Station Terms and Cluster Analysis, in press, *Bull. Seismol. Soc. Am.,* 2005.

Liu, J., K. Sieh, and E. Hauksson, A structural interpretation of the aftershock “cloud” of the 1992 Mw7.3 Landers Earthquake, *Bull. Seismol. Soc. Am., 93*, no. 3, 1333-1344. 2003.

Nazareth, J. J., and E. Hauksson The Seismogenic Thickness of the Southern California Crust, *Bull. Seismol. Soc. Am. 94, 940-960*, 2004.

Woessner, J., Hauksson, E., Wiemer, S., and Neukomm, S.: The 1997 Kagoshima (Japan) Earthquake Doublet: A Quantitative Analysis of Aftershock Rate Changes GRL, *31*, L03605, doi:10.1029/2003GL018858, 2004.

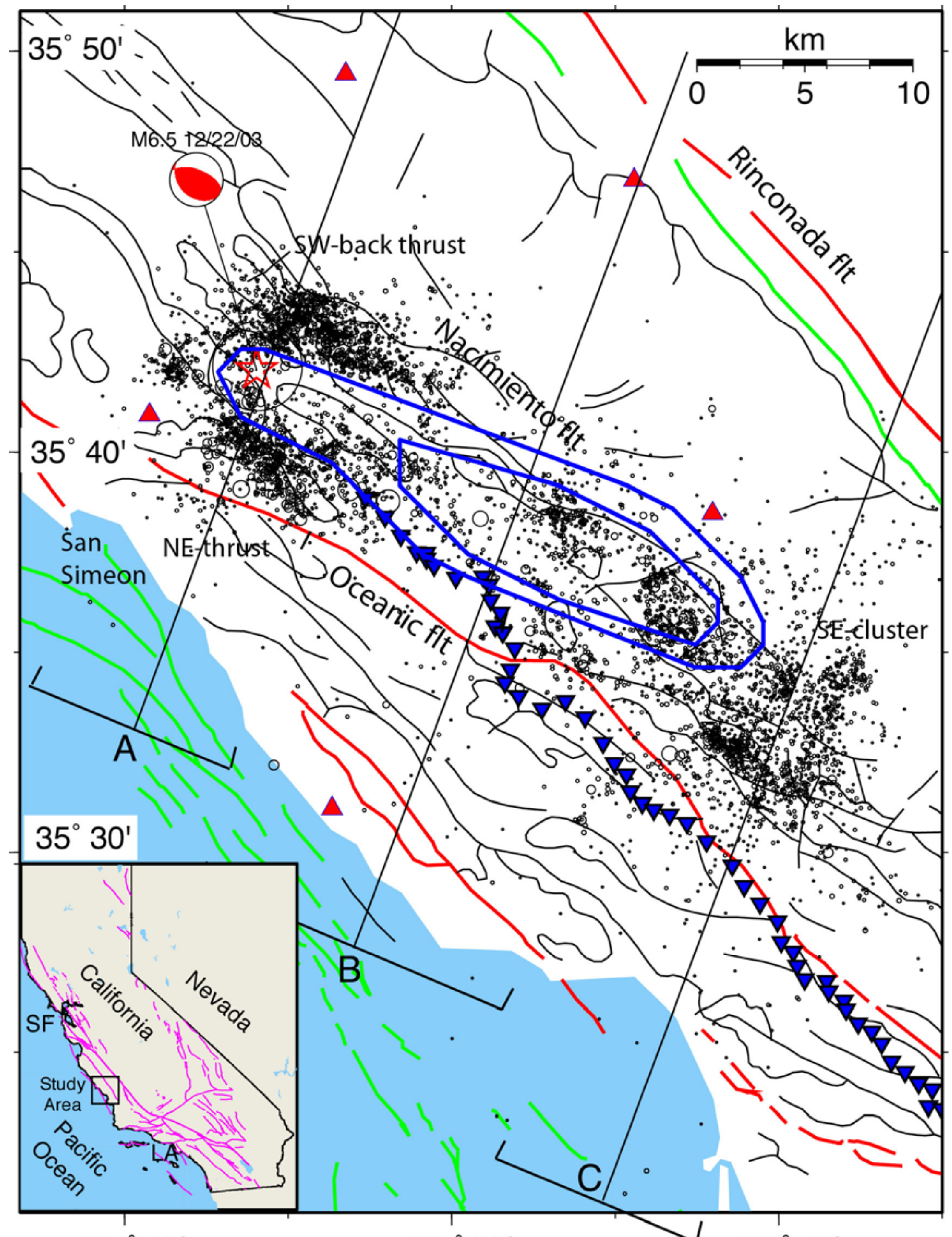

Figure 1. Maps of relocated mainshock-aftershock hypocenters determined with the double-difference method, shown as solid circles. The mainshock epicenter is shown as a red star with the moment tensor from *Hardebeck et al*. [2004], and finite fault model slip contours (blue) from *Ji et al*. [2004]. Major faults from *Jennings* [1994] are shown in red (Holocene and Historic) green (Late Quaternary), and black (pre-Quaternary). Seismic stations (red triangles) and the 1986 refraction line (blue inverted triangles) are also shown. . SF – San Francisco, LA – Los Angeles.

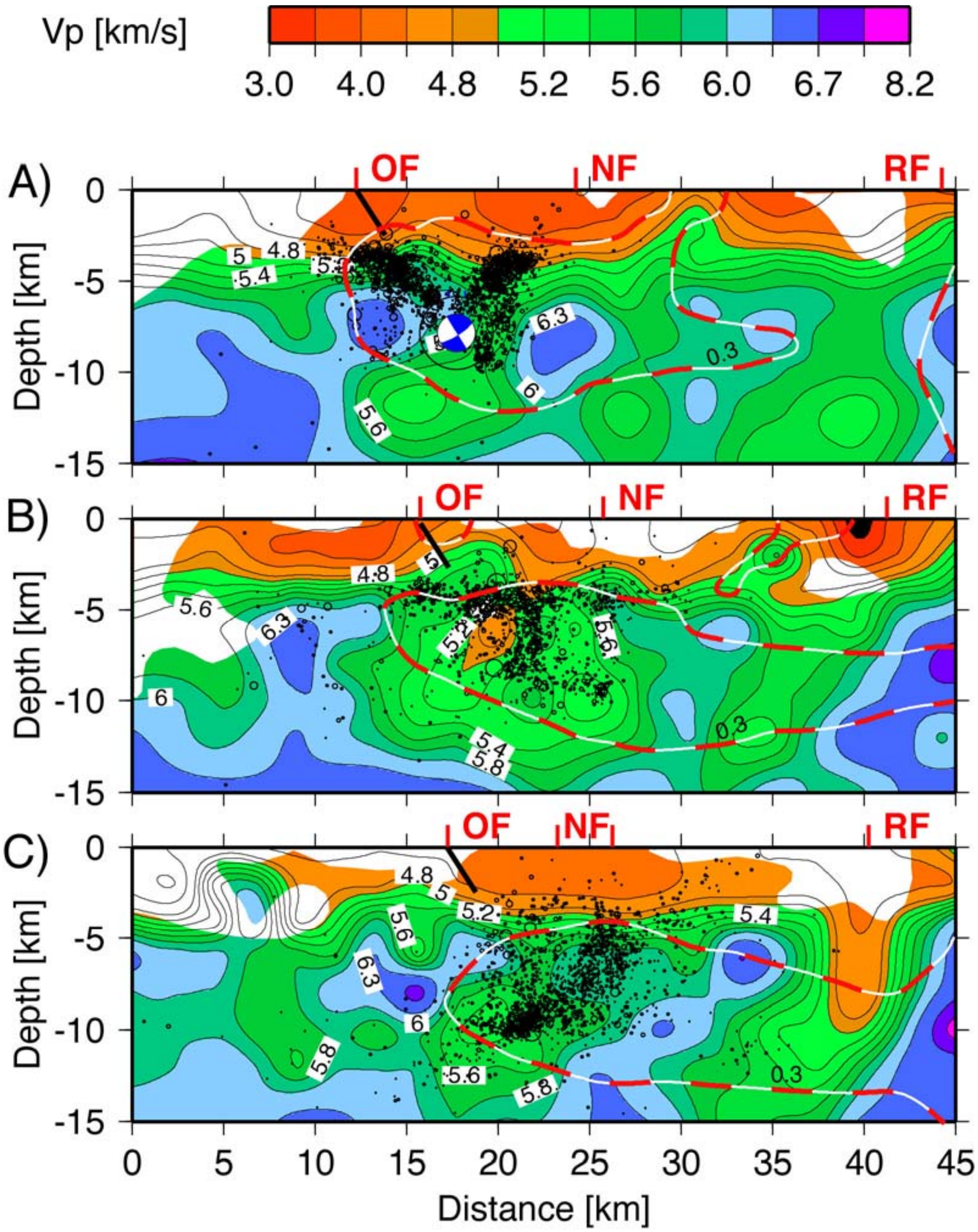

Figure 2. Three depth sections through the Vp model with the relocated aftershocks. The A, B, and C cross sections are indicated by lines, and aftershocks that plot within the brackets are included in the cross sections, see Figure 1. The dipping line projects the Oceanic fault into the model with a 58° dip from the mainshock moment tensor of *Hardebeck et al*. [2004]. OF, Oceanic fault, NF, Nacimiento fault, and RF, Rinconada fault. In cross section A, the mainshock hypocenter is also plotted as the moment tensor from *Hardebeck et al.* [2004]. The 0.3 value of the diagonal element of the resolution matrix is plotted as a dashed (red-white) line. Poorly resolved regions of the model with DWS≤100 are not shown.

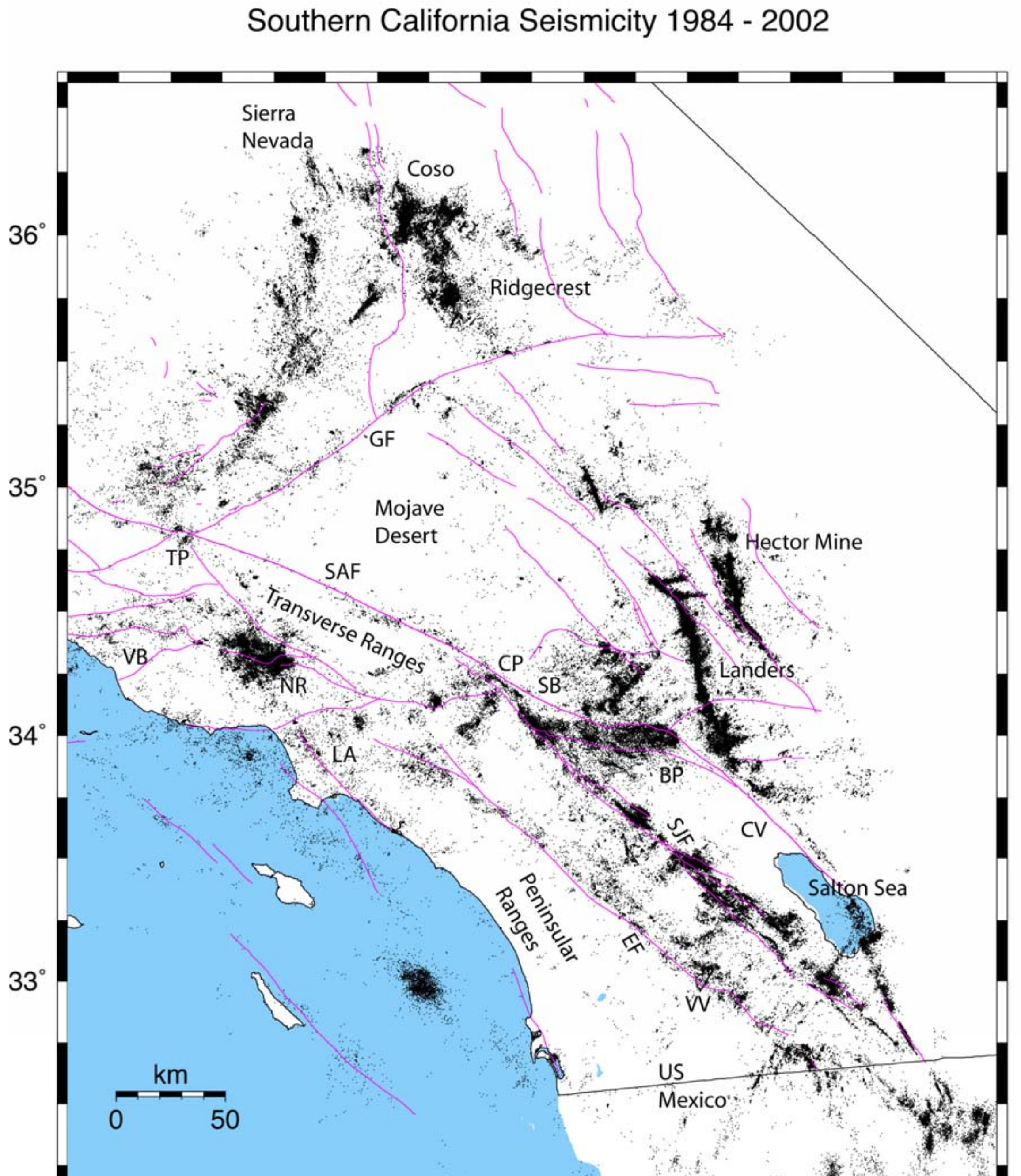

Figure 3. . The relocated southern California seismicity 1984-2002 using the double-difference method. BP – Banning Pass; BS – Brawley seismic zone; CP – Cajon Pass; CV – Coachella Valley; EF – Elsinore fault; GF – Garlock fault; HS – Hollywood-Santa Monica fault; IV – Imperial Valley; LA – Los Angeles; NI – Newport-Inglewood fault; NR – Northridge; SAF-San Andreas fault; SB – San Bernardino Mountains; SJF, San Jacinto fault; TP – Tejon Pass; VB – Ventura Basin; VV- Vallecitos Valley..

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